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**Song et al.**

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(54) **RAISED SOURCE/DRAIN MOS TRANSISTOR AND METHOD OF FORMING THE TRANSISTOR WITH AN IMPLANT SPACER AND AN EPITAXIAL SPACER**

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**H01L 29/78** (2006.01)  
**H01L 29/66** (2006.01)  
**H01L 21/265** (2006.01)  
**H01L 29/08** (2006.01)  
**H01L 29/417** (2006.01)

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(2013.01); **H01L 29/0847** (2013.01); **H01L 29/41783** (2013.01); **H01L 29/6653** (2013.01); **H01L 29/6656** (2013.01); **H01L 29/66628** (2013.01); **H01L 29/7834** (2013.01)

(58) **Field of Classification Search**

CPC ..... H01L 21/823418; H01L 29/41783  
USPC ..... 438/300, 301, 306, 307  
See application file for complete search history.

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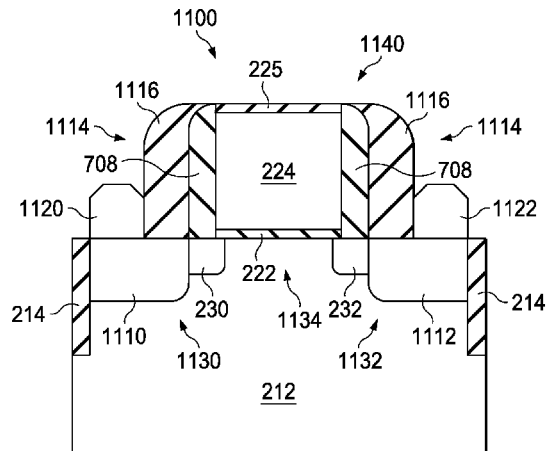
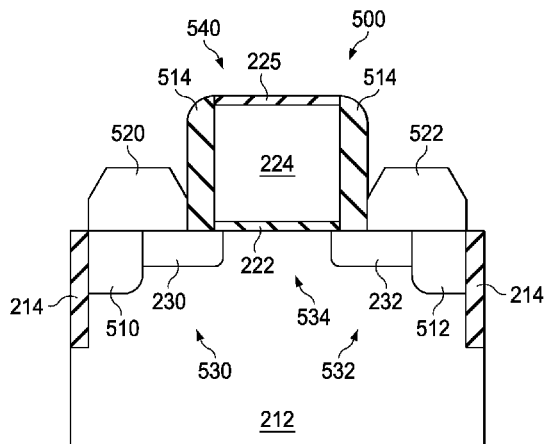
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(57) **ABSTRACT**

A raised source/drain MOS transistor is formed in a process that utilizes a first sidewall spacer when implanting a semiconductor region to form the heavily-doped source region and the heavily-doped drain region of the transistor, and a second different sidewall spacer when epitaxially growing the raised source region and the raised drain region of the transistor.

**3 Claims, 14 Drawing Sheets**



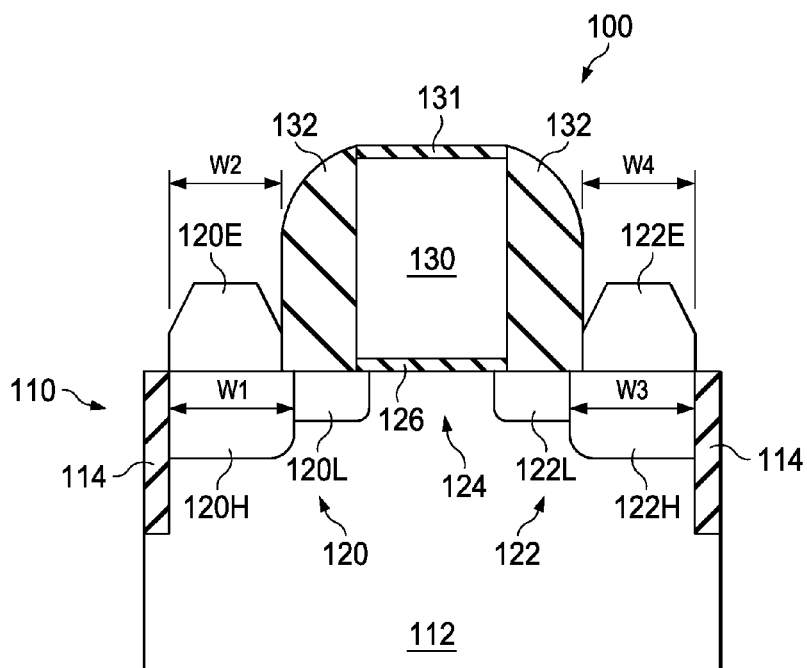


FIG. 1  
(PRIOR ART)

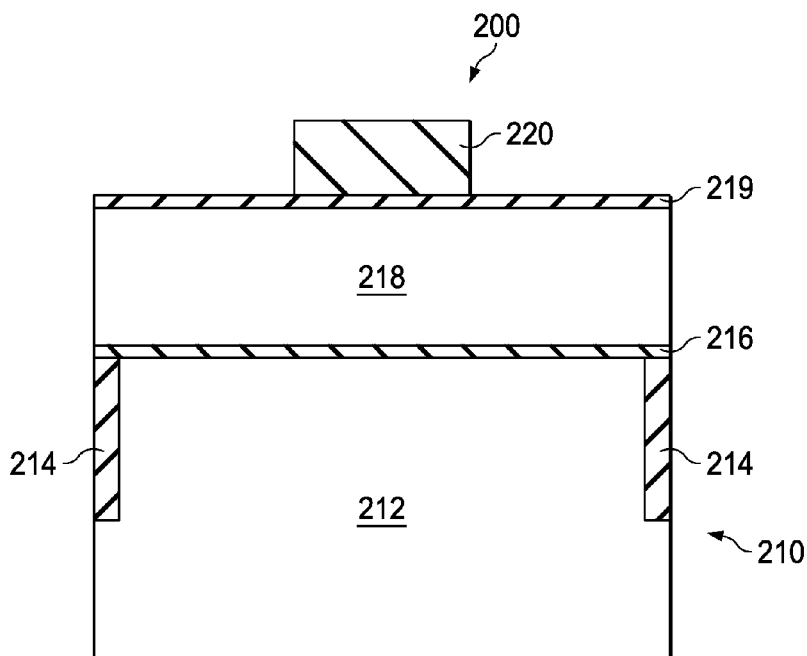


FIG. 2A  
(PRIOR ART)

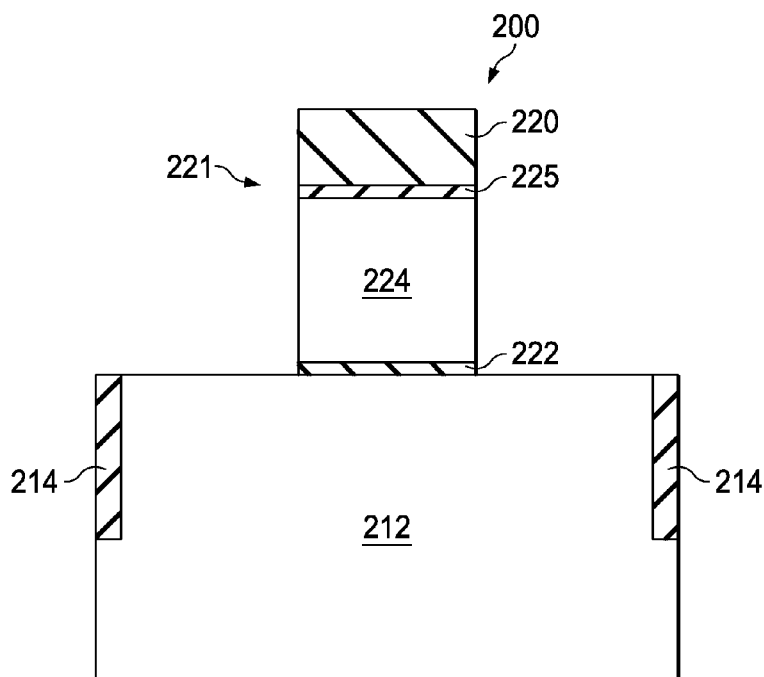


FIG. 2B  
(PRIOR ART)

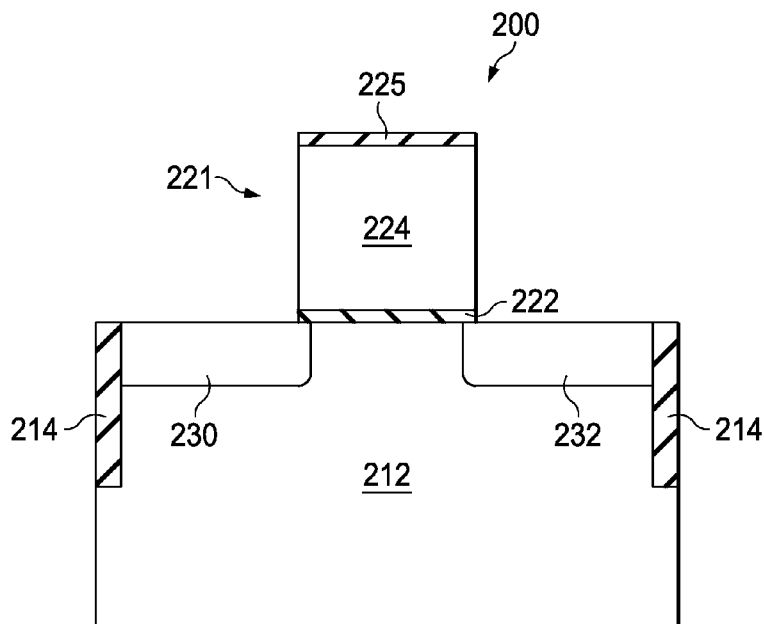


FIG. 2C  
(PRIOR ART)

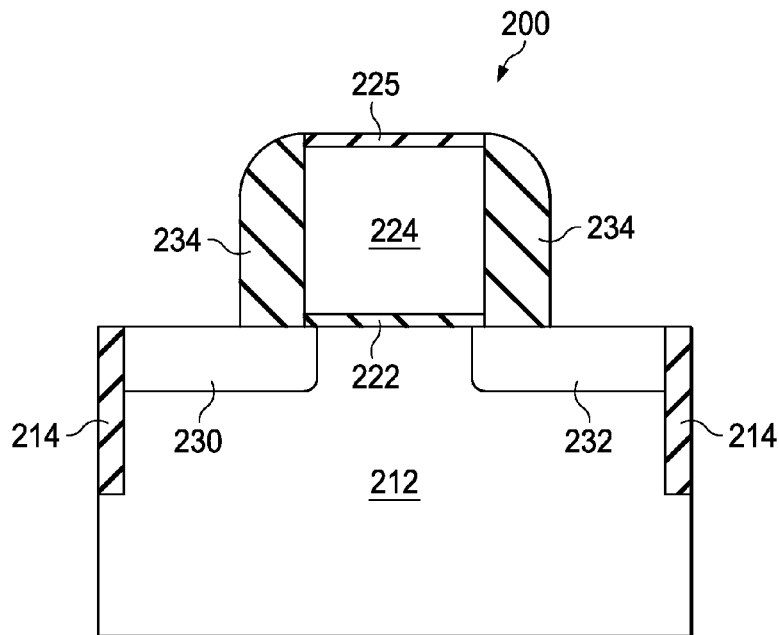


FIG. 2D  
(PRIOR ART)

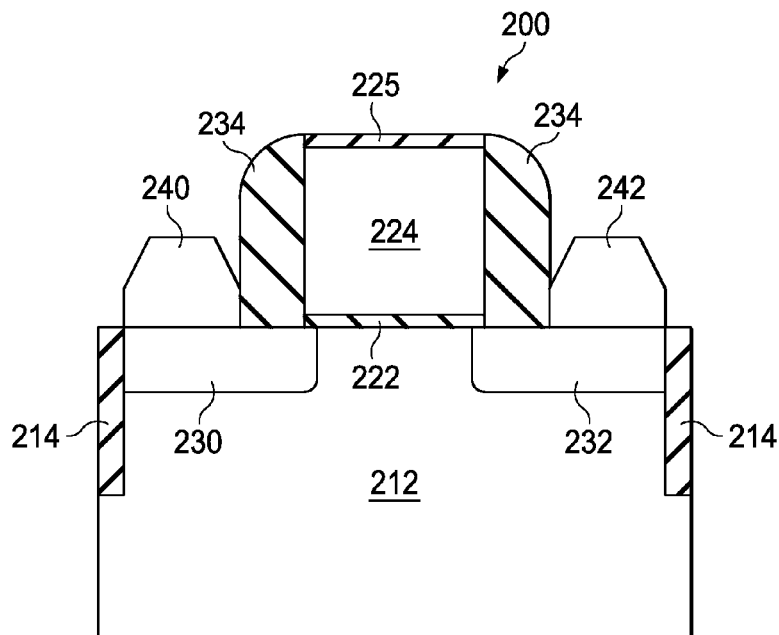


FIG. 2E  
(PRIOR ART)

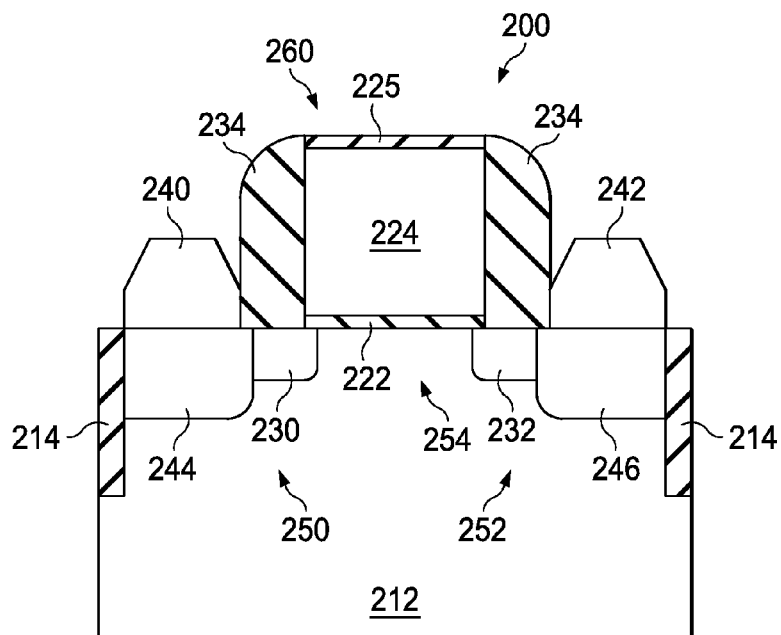


FIG. 2F  
(PRIOR ART)

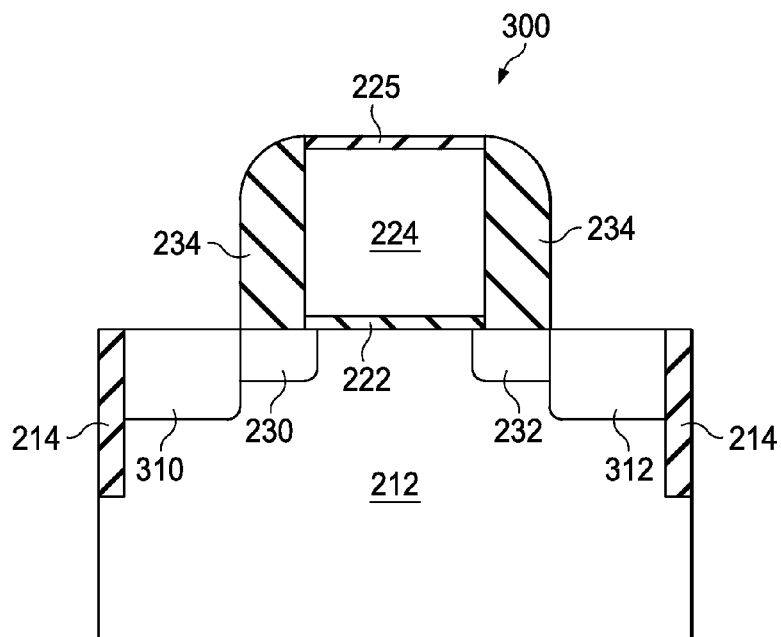


FIG. 3A  
(PRIOR ART)

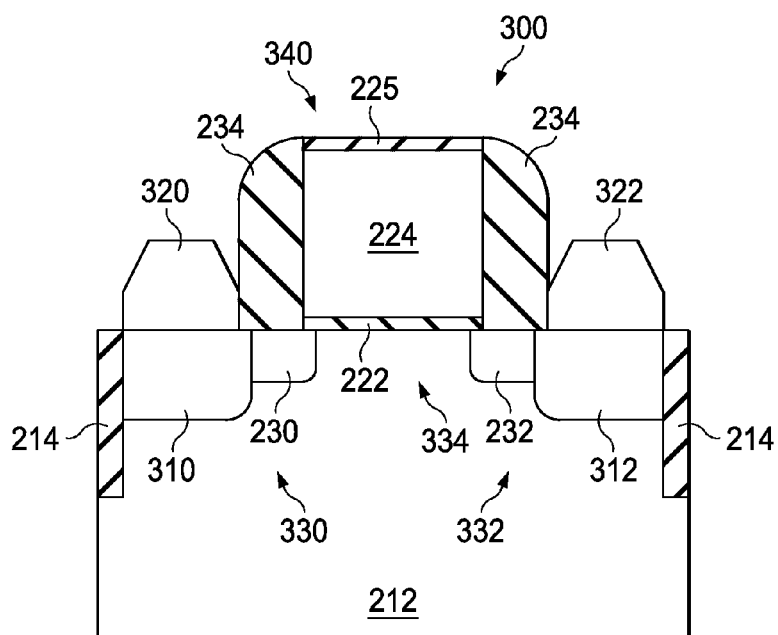


FIG. 3B  
(PRIOR ART)

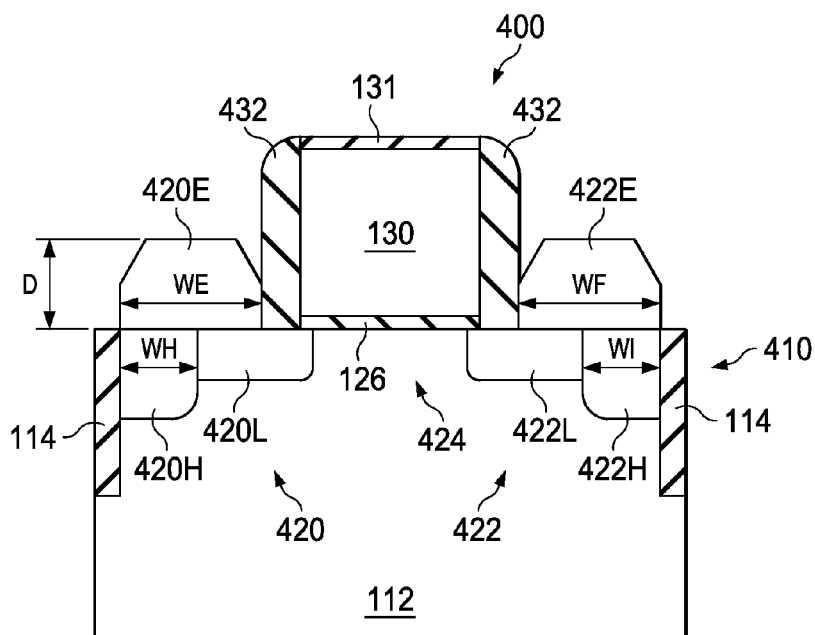


FIG. 4

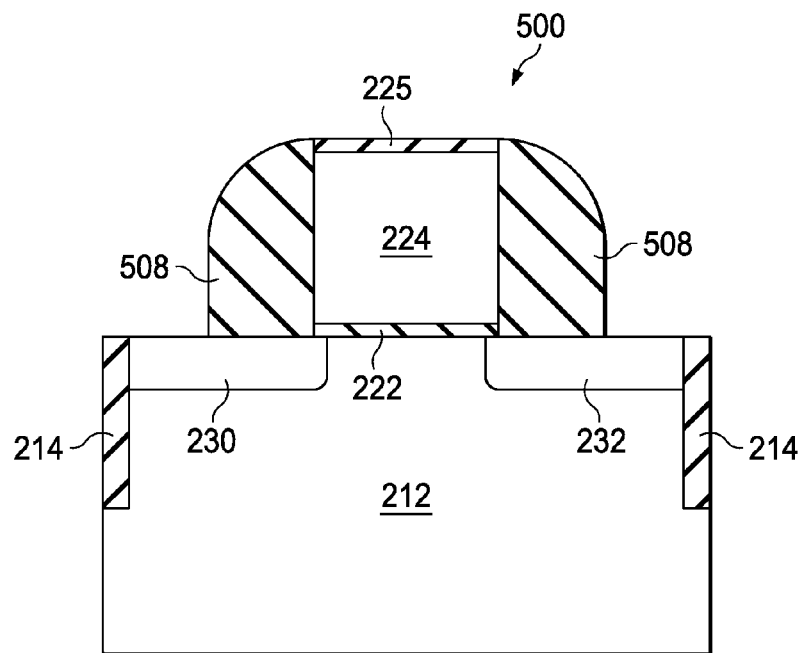


FIG. 5A

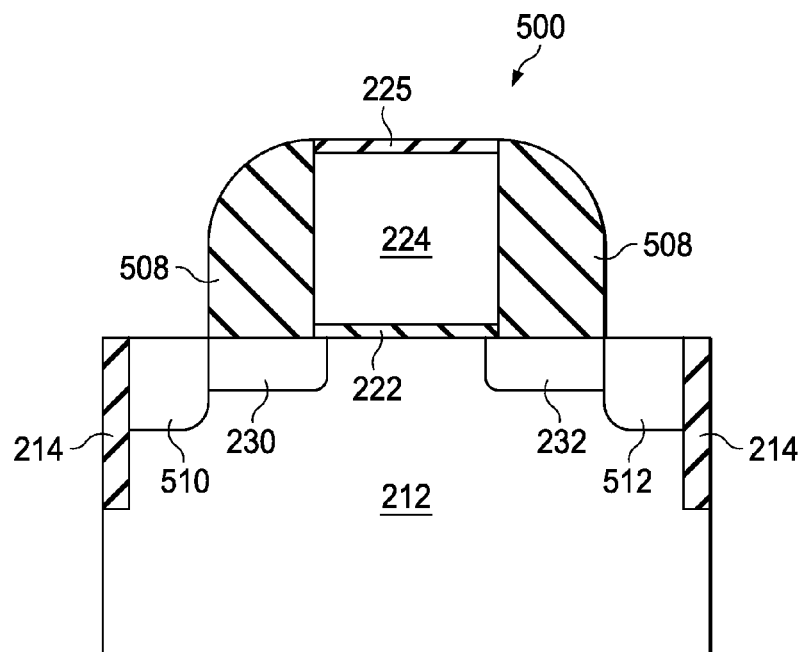


FIG. 5B

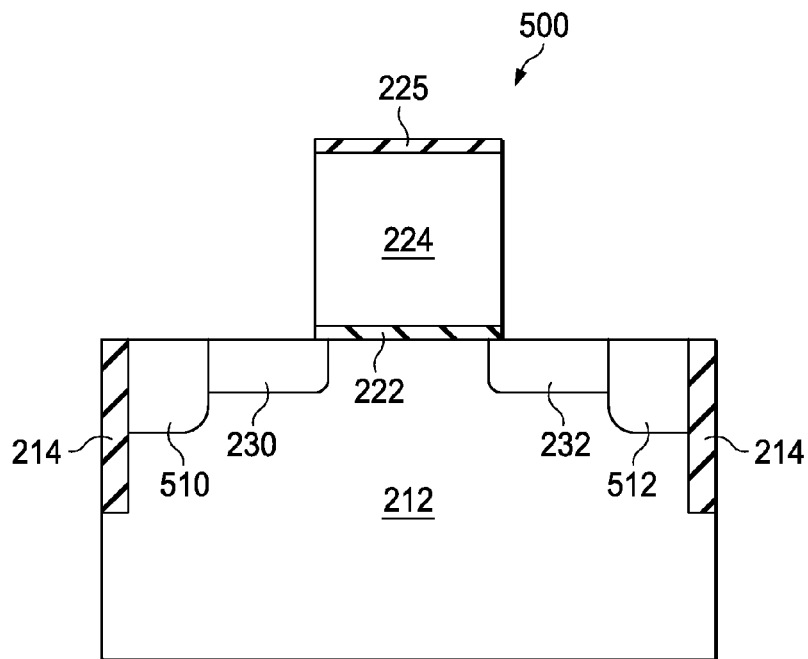


FIG. 5C

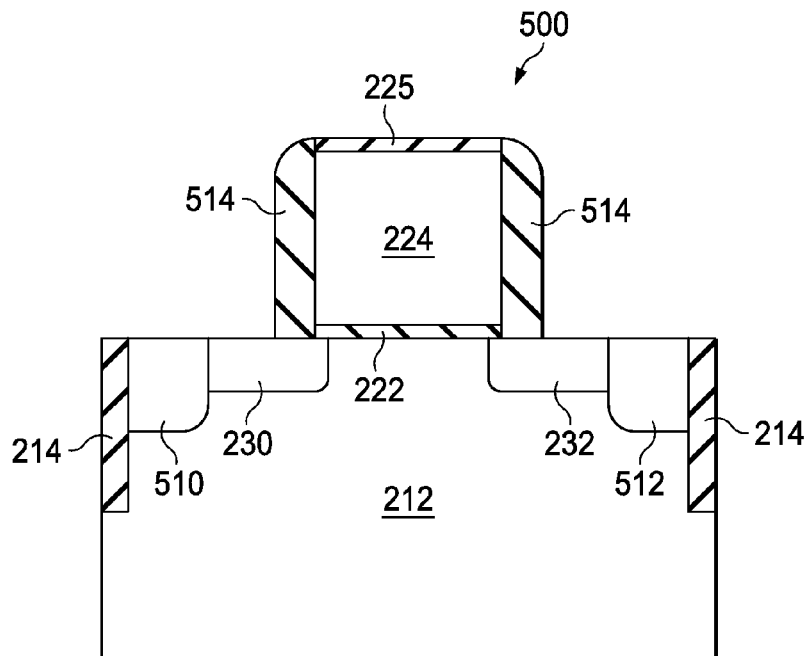


FIG. 5D



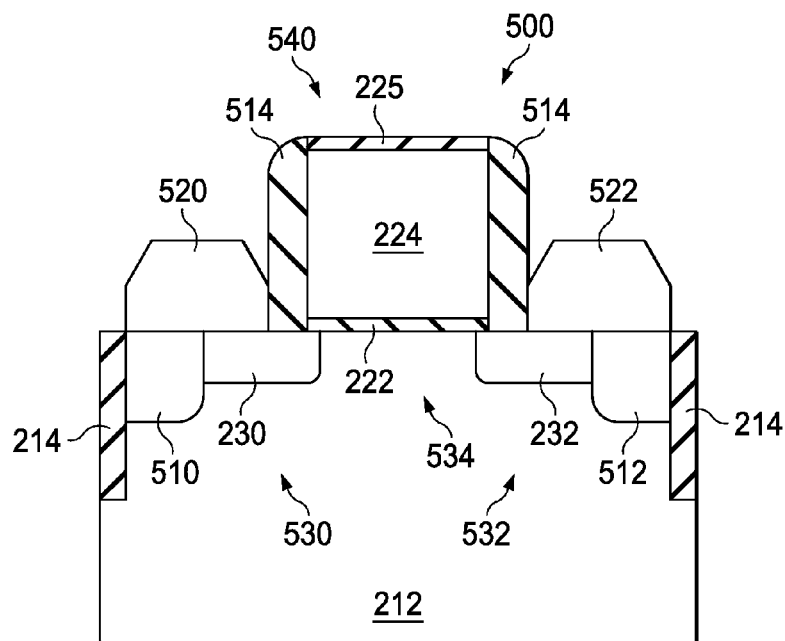


FIG. 5E

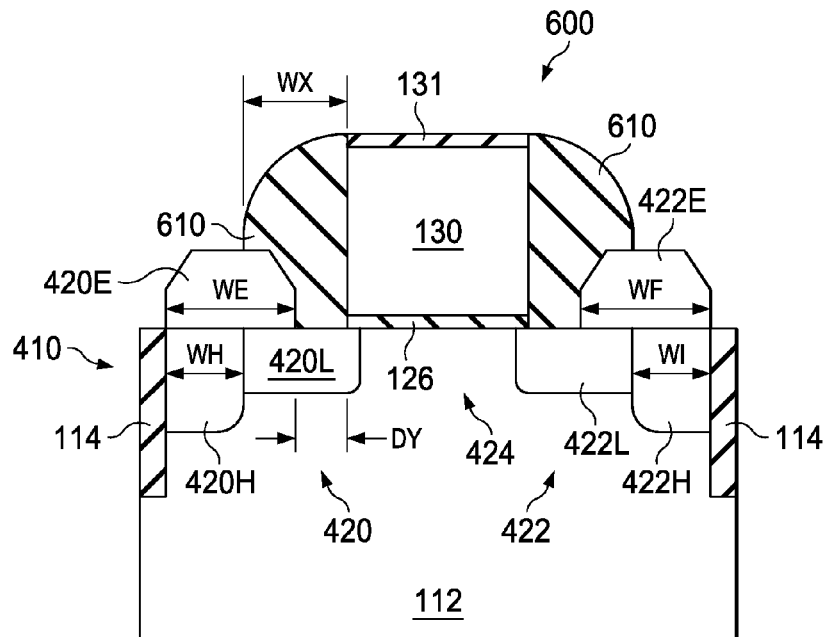


FIG. 6

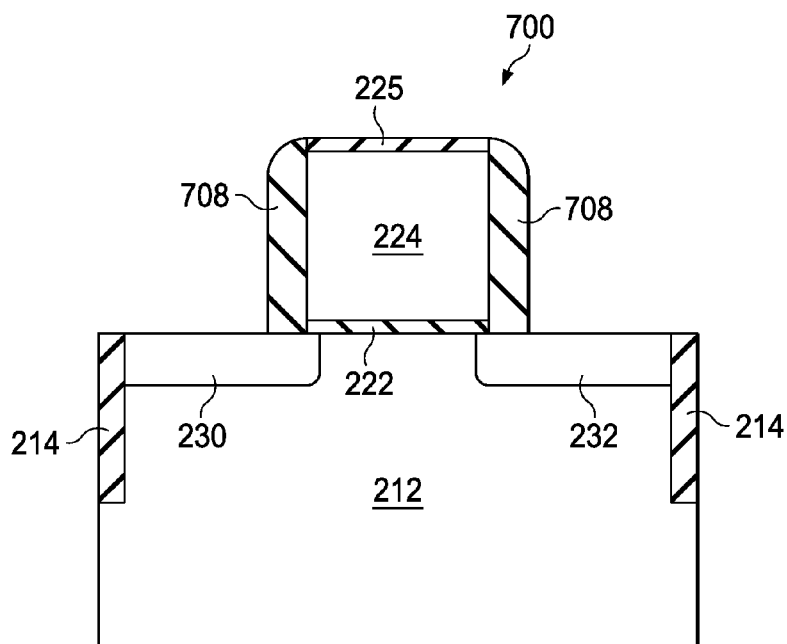


FIG. 7A

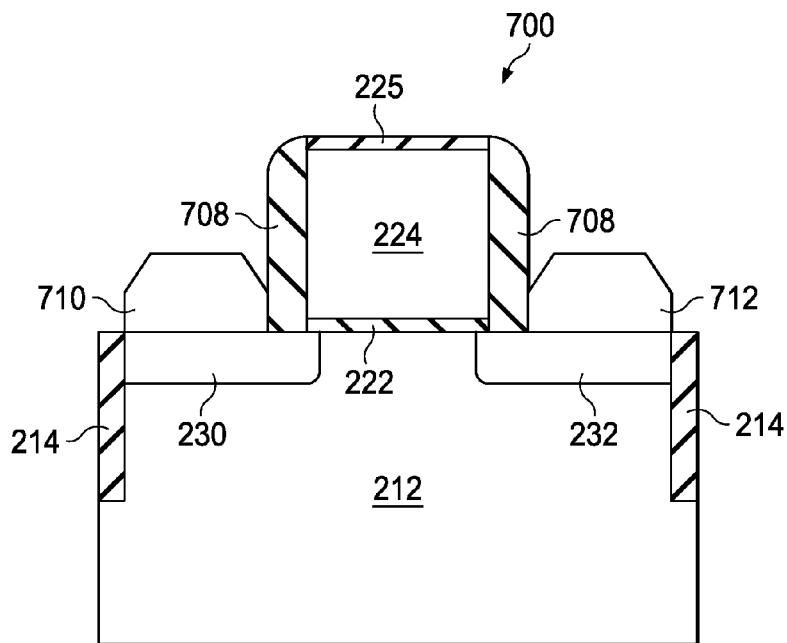


FIG. 7B

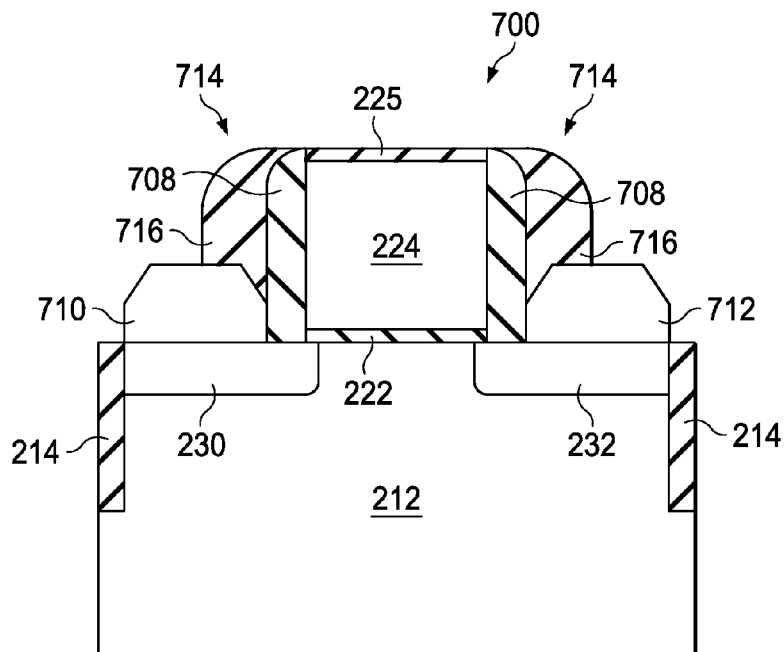


FIG. 7C

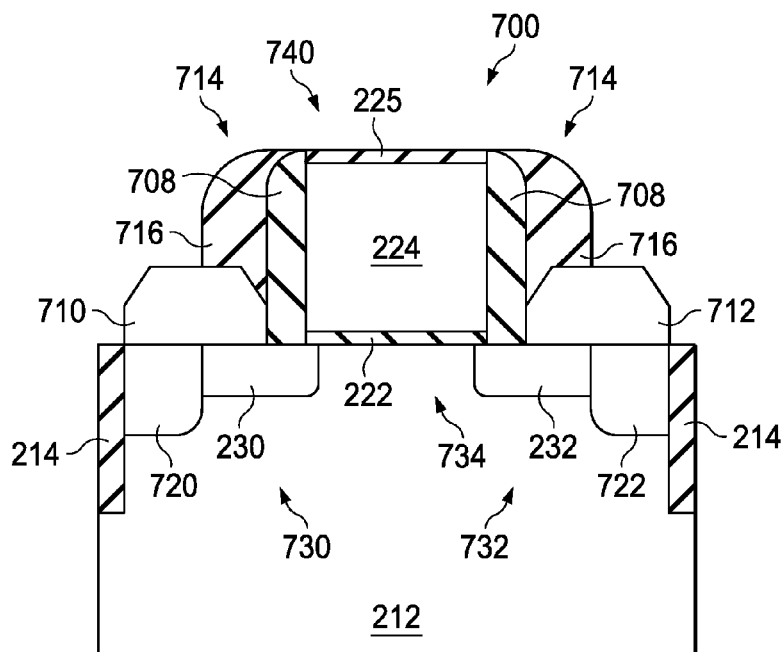


FIG. 7D

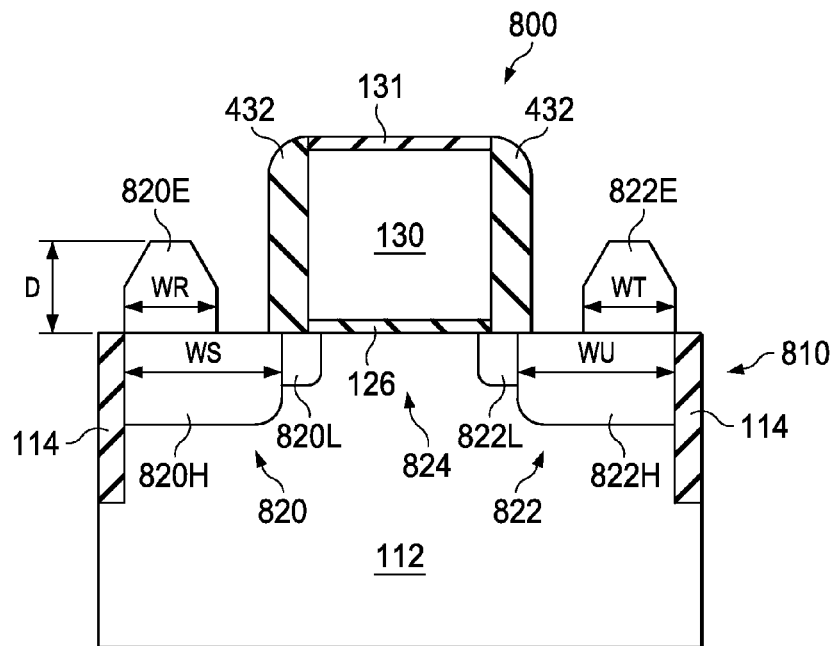


FIG. 8

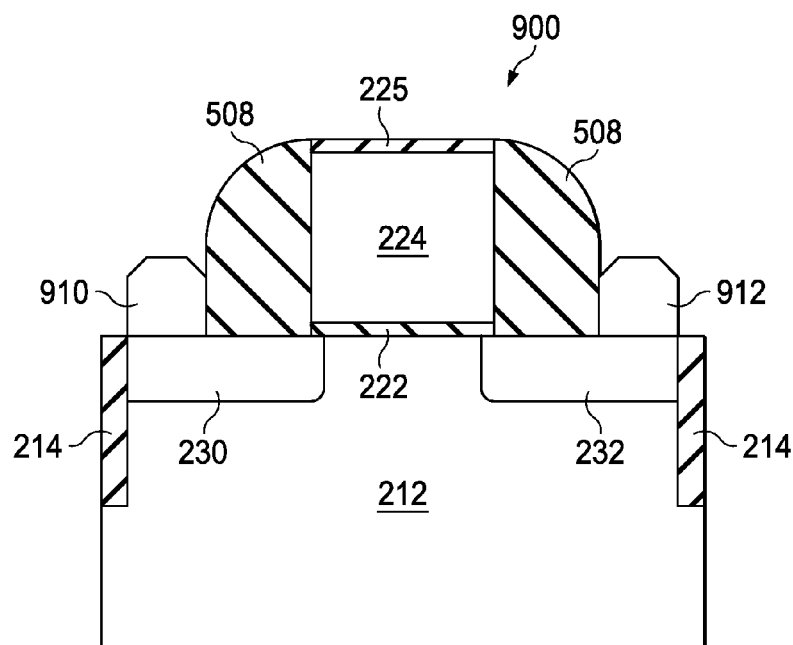


FIG. 9A

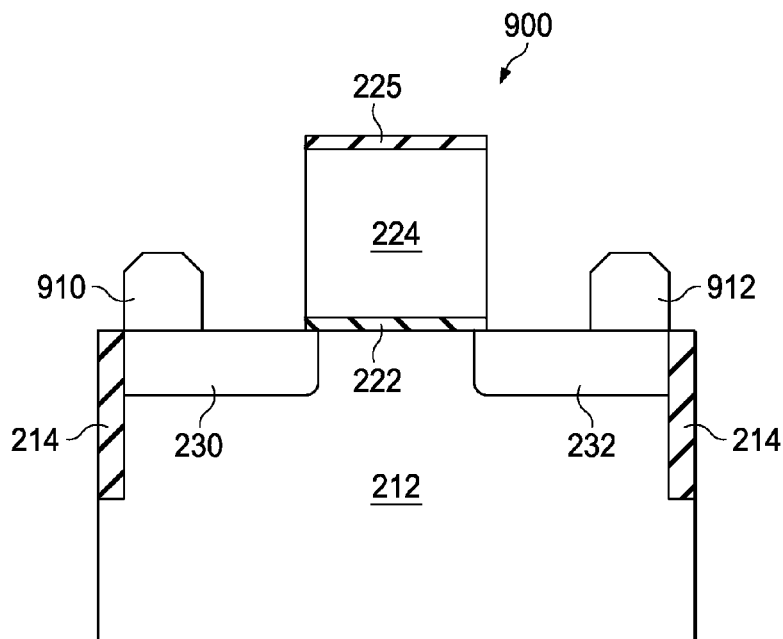


FIG. 9B

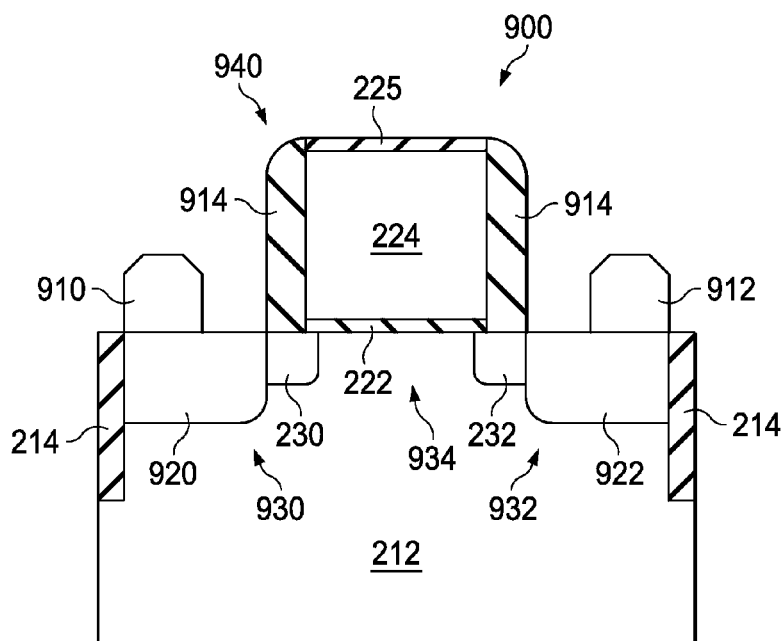


FIG. 9C

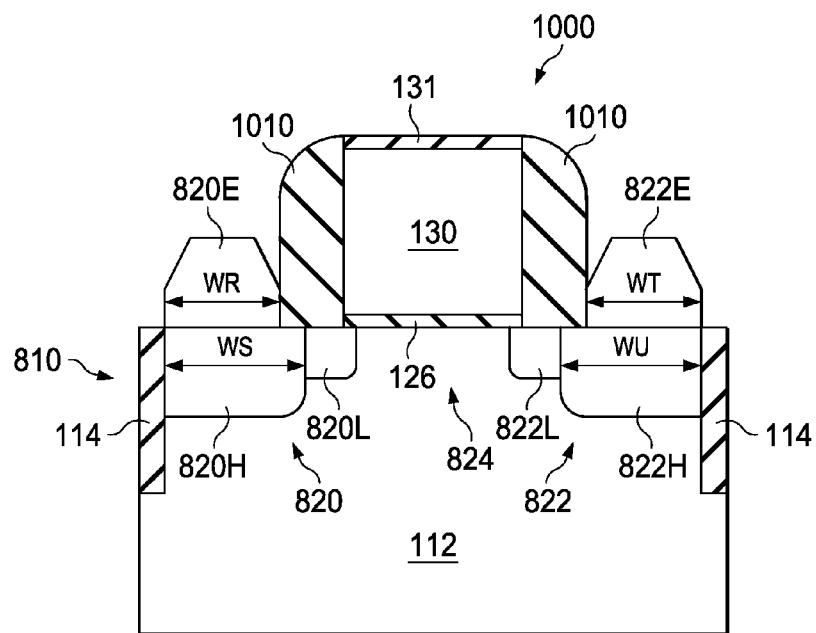


FIG. 10

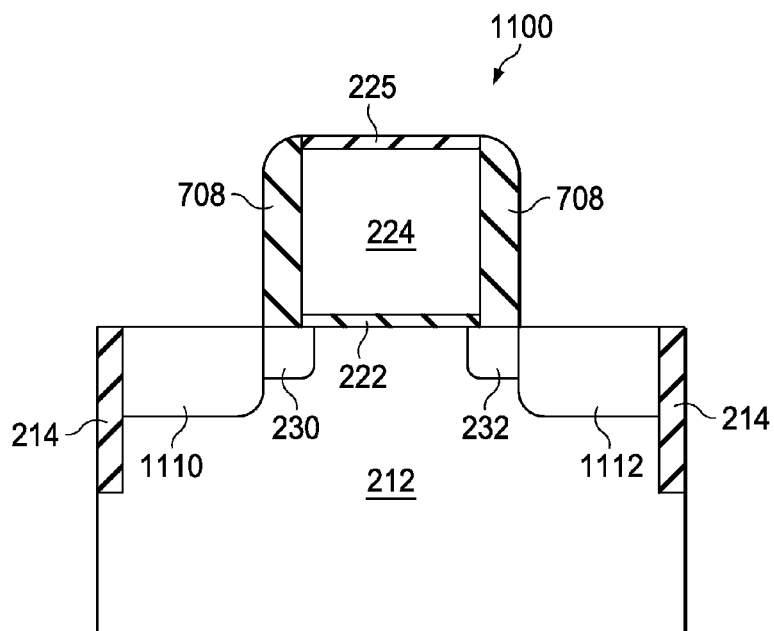


FIG. 11A

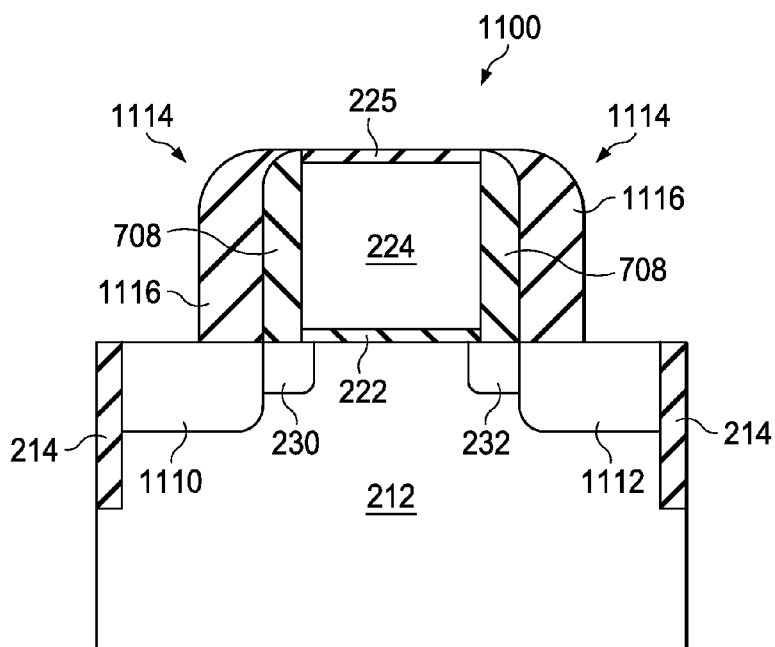


FIG. 11B

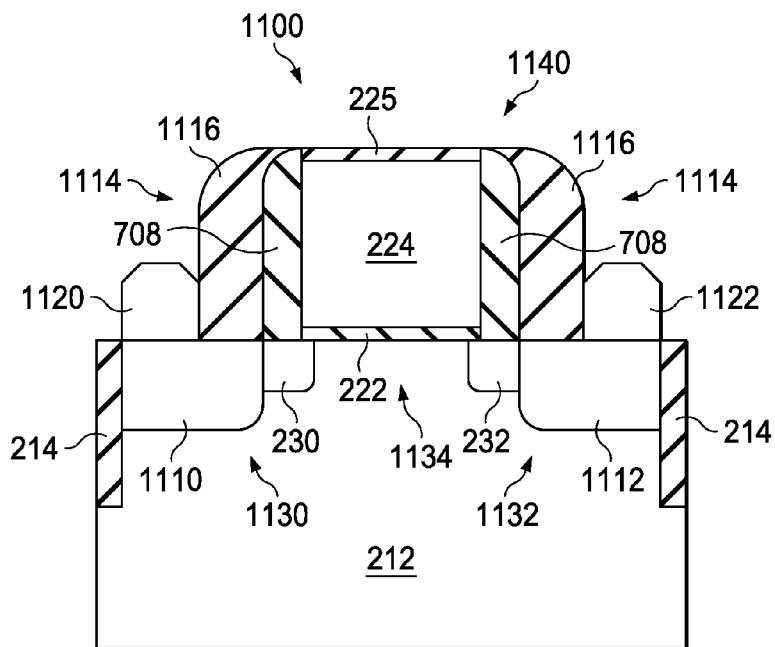


FIG. 11C

1

# RAISED SOURCE/DRAIN MOS TRANSISTOR AND METHOD OF FORMING THE TRANSISTOR WITH AN IMPLANT SPACER AND AN EPITAXIAL SPACER

## CROSS REFERENCE TO RELATED APPLICATIONS

This application is a divisional of U.S. Nonprovisional patent application Ser. No. 13/729,282, filed Dec. 28, 2012, the contents of which are herein incorporated by reference in its entirety.

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The present invention relates to raised source/drain MOS transistors and, more particularly, to a raised source/drain MOS transistor and a method of forming the transistor with an implant spacer and an epitaxial spacer.

### 2. Description of the Related Art

A metal oxide semiconductor (MOS) transistor is a well-known semiconductor device which can be implemented as either an n-channel (NMOS) device or a p-channel (PMOS) device. A MOS transistor has spaced-apart source and drain regions, which are separated by a channel, and a gate that lies over, and is insulated from, the channel by a gate dielectric layer. A raised source/drain MOS transistor is a type of MOS transistor that also includes an epitaxially-grown raised source region and an epitaxially-grown raised drain region.

FIG. 1 shows a cross-sectional view that illustrates a prior-art raised source/drain MOS transistor **100**. As shown in FIG. 1, MOS transistor **100** includes a semiconductor body **110**. Semiconductor body **110**, in turn, includes a single-crystal-silicon substrate region **112**, and a trench isolation structure **114** that touches substrate region **112**.

In addition, semiconductor body **110** includes a source **120** and a drain **122** that each touch substrate region **112**. Source **120** includes a lightly-doped source region **120L**, a heavily-doped source region **120H**, and a raised source region **120E**, each of which has a conductivity type that is the opposite of the conductivity type of substrate region **112**.

Lightly-doped source region **120L** touches substrate region **112**, heavily-doped source region **120H** touches both substrate region **112** and lightly-doped source region **120L**, and raised source region **120E**, which is heavily-doped, touches and lies above the top surface of heavily-doped source region **120H**. Further, heavily-doped source region **120L** has a maximum width  $W_1$  that is slightly, but insubstantially larger, than a maximum width  $W_2$  of raised source region **120E**.

Similarly, drain **122** includes a lightly-doped drain region **122L**, a heavily-doped drain region **122H**, and a raised drain region **122E**, each of which has a conductivity type that is the opposite of the conductivity type of substrate region **112**. Lightly-doped drain region **122L** touches substrate region **112**, heavily-doped drain region **122H** touches both substrate region **112** and lightly-doped drain region **122L**, and raised drain region **122E** touches and lies above the top surface of heavily-doped drain region **122H**.

Further, heavily-doped drain region **122L** has a maximum width  $W_3$  that is slightly, but insubstantially larger, than a maximum width  $W_4$  of raised drain region **122E**. The source **120** and drain **122**, which are spaced apart, also define a channel region **124** of substrate region **112**. Channel region **124**, which has the same conductivity type as substrate region **112**, lies between source **120** and drain **122**.

2

As further shown in FIG. 1, MOS transistor **100** includes a gate dielectric **126** that touches and lies over channel region **124**, and a gate **130** that touches gate dielectric **126** and lies over channel region **124**. MOS transistor **100** also includes a protective cap **131** that touches and lies over gate **130**, and a sidewall spacer **132** that touches and laterally surrounds gate **130** and protective cap **131**. Sidewall spacer **132**, which is non-conductive, also touches the raised source and drain regions **120E** and **122E**.

The threshold voltage of a transistor is the gate voltage required to form an inversion layer at the top surface of the channel region that is sufficient to allow a current to flow from the source region to the drain region. In the case of an NMOS transistor, n-type dopant atoms form the inversion layer, while p-type dopant atoms form the inversion layer in the case of a PMOS transistor.

In operation, with respect to NMOS transistors, when a positive drain-to-source voltage  $V_{DS}$  is present, and the gate-to-source voltage  $V_{GS}$  is more positive than the threshold voltage, the NMOS transistor turns on and electrons flow from the source region to the drain region. When the gate-to-source voltage  $V_{GS}$  is more negative than the threshold voltage, the MOS transistor turns off and no electrons (other than a very small leakage current) flow from the source region to the drain region.

With respect to PMOS transistors, when a negative drain-to-source voltage  $V_{DS}$  is present, and the gate-to-source voltage  $V_{GS}$  is more negative than the threshold voltage, the PMOS transistor turns on and holes flow from the source region to the drain region. When the gate-to-source voltage  $V_{GS}$  is more positive than the threshold voltage, the PMOS transistor turns off and no holes (other than a very small leakage current) flow from the source region to the drain region.

One issue that becomes increasingly important as transistor sizes shrink to, for example, a 50 nm-size, is short channel effects. One approach to controlling short channel effects in conventional 50 nm-sized transistors, which do not have raised source and drain regions, is to utilize very shallow junctions. Very shallow junctions, however, increase the series resistance of the source and the drain. One technique for reducing the series resistance is to reduce the width of the sidewall spacer.

However, when the width of the sidewall spacer is meaningfully reduced, the out diffusion of dopant atoms from the heavily-doped source and drain regions during an anneal commonly consumes and eliminates the lightly-doped source and drain regions which, in turn, reduces the short channel performance.

Raised source/drain MOS transistor **100** differs from conventional 50 nm-sized transistors in that the raised source and drain regions **120E** and **122E** substantially reduce the number of dopant atoms from the heavily-doped source and drain regions **120H** and **122H** that diffuse during the anneal into the lightly-doped source and drain regions **120L** and **122L** that lie below sidewall spacer **132**.

Thus, MOS transistor **100** improves short channel performance because a thin sidewall spacer, which improves short channel performance, is used in combination with the raised source and drain regions **120E** and **122E**, which limit the diffusion of dopant atoms into the lightly-doped source and drain regions **120L** and **122L**, and thereby prevent the lightly-doped source and drain regions **120L** and **122L** from being consumed.

FIGS. 2A-2F show cross-sectional views that illustrate a prior-art method **200** of forming a raised source/drain MOS transistor. As shown in FIG. 2A, method **200** utilizes a con-



ventionally-formed semiconductor body **210** that includes a single-crystal-silicon substrate region **212** and an isolation structure **214** that touches substrate region **212**. As further shown in FIG. 2, method **200** begins by forming a gate dielectric layer **216** that touches and lies over substrate region **212**. Gate dielectric layer **216** can be implemented with, for example, a layer of oxide.

After gate dielectric layer **216** has been formed, a gate layer **218** is formed to touch and lie over gate dielectric layer **216**. Gate layer can be implemented with, for example, a layer of polysilicon. Once gate layer **218** has been formed, a protective layer **219** is formed to touch and lie over gate layer **218**. Protective layer **219** can be implemented with, for example, a layer of nitride. Following this, a patterned mask **220** is formed on protective layer **218** using conventional procedures.

As shown in FIG. 2B, after patterned mask **220** has been formed, the exposed regions of protective layer **219**, underlying gate layer **218**, and underlying gate dielectric layer **216** are etched away in a conventional manner to expose the top surface of substrate region **212** and form a gate structure **221**.

Gate structure **221**, in turn, includes a gate dielectric **222** that touches and lies above substrate region **212**, a gate **224** that touches and lies above gate dielectric **222**, and a protective cap **225** that touches and lies above gate **224**. Following the etch, patterned mask **220** is removed in a conventional manner.

As shown in FIG. 2C, after patterned mask **220** has been removed, a dopant is implanted into substrate region **212** using conventional procedures, followed by an anneal to drive in the implant and form spaced-apart lightly-doped regions **230** and **232**. The lightly-doped regions **230** and **232** have a conductivity type that is opposite to the conductivity type of substrate region **212**.

As shown in FIG. 2D, after the lightly-doped regions **230** and **232** have been formed, a non-conductive side wall spacer **234** is formed in a conventional fashion to touch and laterally surround gate **224** and protective cap **225**. Non-conductive side wall spacer **234** can be formed in a number of ways. For example, a layer of oxide can be deposited on gate **224**, protective cap **225**, lightly-doped source region **230**, and lightly-doped drain region **232**, followed by the anisotropic etch of the layer of oxide until the top surface of protective cap **225** has been exposed to form sidewall spacer **234**.

As shown in FIG. 2E, after side wall spacer **234** has been formed, a raised source region **240** is epitaxially grown on lightly-doped source region **230**, while a raised drain region **242** is epitaxially grown on lightly-doped drain region **232** at the same time. Nothing is epitaxially grown on gate **224** due to the presence of protective cap **225**.

As shown in FIG. 2F, after the raised source region **240** and the raised drain region **242** have been formed, a dopant is implanted into substrate region **212** and the lightly-doped regions **230** and **232** to form spaced-apart heavily-doped source and drain regions **244** and **246**. Raised source region **240** and raised drain region **242** are also doped during the implant.

Following the implant raised source region **240** and heavily-doped source region **244** have substantially equal maximum widths. Similarly, after the implant raised drain region **242** and heavily-doped drain region **246** have substantially equal maximum widths. Further, the raised source and drain regions **240** and **242** and the heavily-doped source and drain regions **244** and **246** each have a conductivity type that is opposite to the conductivity type of substrate region **212**.

Lightly-doped source region **230**, raised source region **240**, and heavily-doped source region **244** form a source **250**,

while lightly-doped drain region **232**, raised drain region **242**, and heavily-doped region **246** form a drain **252**. The source and drain **250** and **252** define a channel region **254** of substrate region **212** that lies between and separates the source and drain **250** and **252**. Further, the implant also forms a MOS transistor structure **260**.

Following this, MOS transistor structure **260** is again annealed to drive in the implant. The anneal causes the heavily-doped source and drain regions **244** and **246** to expand slightly into the lightly-doped source and drain regions **230** and **232** due to out diffusion. As a result, the maximum width of heavily-doped source region **244** is slightly larger than the maximum width of raised source region **240**.

However, since the only difference in the maximum widths is due to out diffusion, the maximum width of heavily-doped source region **244** is insubstantially larger than the maximum width of raised source region **240**. Similarly, the maximum width of heavily-doped drain region **246** is slightly larger than the maximum width of raised drain region **242** due to out diffusion. However, since the only difference in the maximum widths is due to out diffusion, the maximum width of heavily-doped drain region **246** is insubstantially larger than the maximum width of raised drain region **242**. Following this, method **200** continues with conventional steps.

FIGS. 3A-3B show cross-sectional views that illustrate an alternate prior-art method **300** of forming a raised source/drain MOS transistor. Method **300** is similar to method **200** and, as a result, utilizes the same reference numerals to designate the structures that are common to both methods.

Method **300** is the same as method **200** up through the formation of sidewall spacer **234** shown in FIG. 2D, and differs from method **200** in that, as shown in FIG. 3A, method **300** next implants a dopant into substrate region **212** and the lightly-doped source and drain regions **230** and **232** to form spaced-apart heavily-doped source and drain regions **310** and **312**.

As shown in FIG. 3B, after the heavily-doped source and drain regions **310** and **312** have been formed, a raised source region **320** is epitaxially grown on heavily-doped source region **310**, while a raised drain region **322** is epitaxially grown on heavily-doped drain region **312** at the same time.

Lightly-doped source region **230**, raised source region **320**, and heavily-doped source region **310** form a source **330**, while lightly-doped drain region **232**, raised drain region **322**, and heavily-doped drain region **312** form a drain **332**. The source and drain regions **330** and **332** form a channel region **334** in substrate region **212** that lies between and separates the source and drain regions **330** and **332**. Further, the implant also forms a MOS transistor structure **340**.

Following this, MOS transistor structure **340** is again annealed to drive in the heavily-doped implant. The anneal causes the heavily-doped source and drain regions **310** and **312** to expand slightly into the lightly-doped source and drain regions **230** and **232** due to out diffusion. As a result, the maximum width of heavily-doped source region **310** is slightly, but insubstantially larger, than the maximum width of raised source region **320**. Similarly, the maximum width of heavily-doped drain region **312** is slightly, but insubstantially larger, than the maximum width of raised drain region **322**. Following this, method **300** continues with conventional steps.

Although method **200** and method **300** illustrate approaches for fabricating a raised source/drain MOS tran-

5

sistor, there is a need for additional approaches to fabricating raised source/drain MOS transistors.

#### SUMMARY OF THE INVENTION

The present invention provides a raised source/drain MOS transistor and a method of forming the transistor that optimize the positions of the heavily-doped source and drain regions with respect to the positions of the raised source and drain regions. A semiconductor structure of the present invention includes a semiconductor region that has a conductivity type. The semiconductor structure also includes a source that has a conductivity type that is opposite to the conductivity type of the semiconductor region. The source includes a lightly-doped source region that touches the semiconductor region, a heavily-doped source region that touches the lightly-doped source region, and a raised source region that touches the heavily-doped source region. The heavily-doped source region has a width, and the raised source region has a width. The width of the raised source region is greater than the width of the heavily-doped source region. In addition, the semiconductor structure includes a drain that has a conductivity type that is opposite to the conductivity type of the semiconductor region. The drain includes a lightly-doped drain region that touches the semiconductor region, a heavily-doped drain region that touches the lightly-doped drain region, and a raised drain region that touches the heavily-doped drain region. Further, the semiconductor structure includes a channel region of the semiconductor region that lies laterally between the source and the drain. The semiconductor structure additionally includes a gate dielectric that touches and lies over the channel region, and a gate that touches and lies over the gate dielectric.

A semiconductor structure in an alternate embodiment of the present invention includes a semiconductor region that has a conductivity type. The semiconductor structure also includes a source that has a conductivity type that is opposite to the conductivity type of the semiconductor region. The source includes a lightly-doped source region that touches the semiconductor region, a heavily-doped source region that touches the lightly-doped source region, and a raised source region that touches the heavily-doped source region. The heavily-doped source region has a width, and the raised source region has a width. The width of the heavily-doped source region is substantially greater than the width of the raised source region. In addition, the semiconductor structure includes a drain that has a conductivity type that is opposite to the conductivity type of the semiconductor region. The drain includes a lightly-doped drain region that touches the semiconductor region, a heavily-doped drain region that touches the lightly-doped drain region, and a raised drain region that touches the heavily-doped drain region. Further, the semiconductor structure includes a channel region of the semiconductor region that lies laterally between the source and the drain. The semiconductor structure additionally includes a gate dielectric that touches and lies over the channel region, and a gate that touches and lies over the gate dielectric.

A method of forming a semiconductor structure in the present invention includes forming a gate structure that includes a gate dielectric that touches and lies above a semiconductor region, and a gate that touches and lies above the gate dielectric. The method also includes implanting the semiconductor region after the gate structure has been formed to form a lightly-doped source region and a lightly-doped drain region that touch the semiconductor region. The method further includes forming a first sidewall spacer that touches and laterally surrounds the gate structure. In addition, the

6

method includes implanting the semiconductor region, the lightly-doped source region, and the lightly-doped drain region after the first sidewall spacer has been formed to form a heavily-doped source region and a heavily-doped drain region. The heavily-doped source region touches the semiconductor region and the lightly-doped source region. The heavily-doped drain region touches the semiconductor region and the lightly-doped drain region. The method additionally includes forming a second sidewall spacer that touches and laterally surrounds the gate structure after the heavily-doped source region and the heavily-doped drain region have been formed. Further, the method includes epitaxially growing a raised source region that touches the heavily-doped source region, and a raised drain region that touches the heavily-doped drain region after the second sidewall spacer has been formed.

A method of forming a semiconductor structure in an alternate embodiment of the present invention includes forming a gate structure that includes a gate dielectric that touches and lies above a semiconductor region, and a gate that touches and lies above the gate dielectric. The method also includes implanting the semiconductor region after the gate structure has been formed to form a lightly-doped source region and a lightly-doped drain region that touch the semiconductor region. The method additionally includes forming a first sidewall spacer that touches and laterally surrounds the gate structure. The method further includes epitaxially growing a raised source region that touches the lightly-doped source region, and a raised drain region that touches the lightly-doped drain region after the first sidewall spacer has been formed. In addition, the method includes forming a second sidewall spacer that touches and laterally surrounds the gate structure after the raised source region and the raised drain region have been formed. Further, the method includes implanting the semiconductor region, the lightly-doped source region, and the lightly-doped drain region after the second sidewall spacer has been formed to form a heavily-doped source region and a heavily-doped drain region. The heavily-doped source region touches the semiconductor region, the lightly-doped source region, and the raised source region. The heavily-doped drain region touches the semiconductor region, the lightly-doped drain region, and the raised drain region.

A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description and accompanying drawings which set forth an illustrative embodiment in which the principals of the invention are utilized.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view illustrating a prior-art raised source/drain MOS transistor **100**.

FIGS. 2A-2F are cross-sectional views illustrating a prior-art method **200** of forming a raised source/drain MOS transistor.

FIGS. 3A-3B are cross-sectional views illustrating an alternate prior-art method **300** of forming a raised source/drain MOS transistor.

FIG. 4 is a cross-sectional view illustrating an example of a raised source/drain MOS transistor **400** in accordance with the present invention.

FIGS. 5A-5E are cross-sectional views illustrating an example of a method **500** of forming a raised source/drain MOS transistor in accordance with the present invention.

FIG. 6 is a cross-sectional view illustrating an example of a raised source/drain MOS transistor **600** in accordance with an alternate embodiment of the present invention.

FIGS. 7A-7D are cross-sectional views illustrating an example of a method **700** of forming a raised source/drain MOS transistor in accordance with an alternate embodiment of the present invention.

FIG. 8 is a cross-sectional view illustrating an example of a raised source/drain MOS transistor **800** in accordance with an alternate embodiment of the present invention.

FIGS. 9A-9C are cross-sectional views illustrating an example of a method **900** of forming a raised source/drain MOS transistor in accordance with an alternate embodiment of the present invention.

FIG. 10 is a cross-sectional view illustrating an example of a raised source/drain MOS transistor **1000** in accordance with an alternate embodiment of the present invention.

FIGS. 11A-11C are cross-sectional views illustrating an example of a method **1100** of forming a raised source/drain MOS transistor in accordance with an alternate embodiment of the present invention.

#### DETAILED DESCRIPTION OF THE INVENTION

FIG. 4 shows a cross-sectional view that illustrates an example of a raised source/drain MOS transistor **400** in accordance with the present invention. As described in greater detail below, the present invention utilizes two different sidewall spacers to independently set the positions of the heavily-doped source and drain regions, and the raised source and drain regions.

MOS transistor **400** is similar to MOS transistor **100** and, as a result, utilizes the same reference numerals to designate the structures which are common to both transistors. As shown in FIG. 4, MOS transistor **400** differs from MOS transistor **100** in that MOS transistor **400** utilizes a body **410** in lieu of body **110**. Body **410**, in turn, is the same as body **110** except that body **410** utilizes a source **420** in lieu of source **120**.

Source **420** includes a lightly-doped source region **420L**, a heavily-doped source region **420H**, and a raised source region **420E**, each of which has a conductivity type that is the opposite of the conductivity type of substrate region **112**. Lightly-doped source region **420L** touches substrate region **112**, and heavily-doped source region **420H** touches both substrate region **112** and lightly-doped source region **420L**. In addition, raised source region **420E**, which is heavily-doped, touches and lies above the top surface of heavily-doped source region **420H**.

Further, raised source region **420E** has a maximum width **WE**, a maximum depth **D** that is orthogonal to the maximum width **WE**, and a length that is orthogonal to the maximum width **WE** and the maximum depth **D**. Heavily-doped source region **420H** also has a maximum width **WH**, a depth measured parallel to the maximum depth **D**, and a length measured parallel to the length of raised source region **420E**.

As additionally shown in FIG. 4, the maximum width **WE** of raised source region **420E** is larger than the maximum width **WH** of heavily-doped source region **420H**. In addition, a portion of raised source region **420E** lies directly vertically over a portion of lightly-doped source region **420L**.

Body **410** also differs from body **110** in that body **410** utilizes a drain **422** in lieu of drain **122**. Drain **422** includes a lightly-doped drain region **422L**, a heavily-doped drain region **422H**, and a raised drain region **422E**, each of which has a conductivity type that is the opposite of the conductivity type of substrate region **112**.

Lightly-doped drain region **422L** touches substrate region **112**, and heavily-doped drain region **422H** touches both substrate region **112** and lightly-doped drain region **422L**. Raised drain region **422E**, which is heavily doped, touches and lies above the top surface of heavily-doped drain region **422H**. In addition, the top surface of raised source region **420E** and the top surface of the raised drain region **422E** lie in a plane that passes through gate **130**, where the plane lies above the bottom surface of gate **130**.

Further, raised drain region **422E** has a maximum width **WF**, a maximum depth measured parallel to the maximum depth **D**, and a length measured parallel to the length of raised source region **420E**. Heavily-doped drain region **422H** also has a maximum width **WI**, a depth measured parallel to the maximum depth **D**, and a length measured parallel to the length of raised source region **420E**.

As additionally shown in FIG. 4, the maximum width **WF** of raised drain region **422E** is larger than the maximum width **WI** of heavily-doped drain region **422H**. In addition, a portion of raised drain region **420E** lies directly vertically over a portion of lightly-doped drain region **422L**.

The source **420** and drain **422**, which are spaced apart, also define a channel region **424** at the top surface of substrate region **112** that lies between and separates source **420** and drain **422**. In addition, since channel region **424** is a part of substrate region **112**, channel region **424** has the same conductivity type as substrate region **112**.

As further shown in FIG. 4, MOS transistor **400** also differs from MOS transistor **100** in that MOS transistor **400** utilizes a sidewall spacer **432** in lieu of sidewall spacer **132**. Sidewall spacer **432**, which touches the raised source and drain regions **420E** and **422E**, is the same as sidewall spacer **132** except that sidewall spacer **432** is thinner than sidewall spacer **132**.

FIGS. 5A-5E show cross-sectional views that illustrate an example of a method **500** of forming a raised source/drain MOS transistor in accordance with the present invention. Method **500** is similar to method **200** and, as a result, utilizes the same reference numerals to designate the structures that are common to both methods.

Method **500** is the same as method **200** up through the formation of the lightly-doped source and drain regions **230** and **232** shown in FIG. 2C, and differs from method **200** in that, as shown in FIG. 5A, method **500** next forms a wide sidewall spacer **508** to touch and laterally surround gate **224** and protective cap **225**.

Wide side wall spacer **508**, which is non-conductive, can be formed in a number of ways. For example, a thick layer of oxide can be deposited on gate **224**, protective cap **225**, lightly-doped source region **230**, and lightly-doped drain region **232**, followed by the anisotropic etch of the thick layer of oxide until the top surface of protective cap **225** has been exposed to form wide sidewall spacer **508**.

As shown in FIG. 5B, after wide sidewall spacer **508** has been formed, a dopant is implanted into substrate region **212** and the lightly-doped source and drain regions **230** and **232** using conventional procedures to form spaced-apart heavily-doped source and drain regions **510** and **512**. Heavily-doped source region **510** touches both substrate region **212** and lightly-doped source region **230**, while heavily-doped drain region **512** touches both substrate region **212** and lightly-doped drain region **232**.

As shown in FIG. 5C, after the heavily-doped regions **510** and **512** have been formed, wide sidewall spacer **508** is removed using conventional etchants and procedures. As shown in FIG. 5D, after wide sidewall spacer **508** has been removed, a thin sidewall spacer **514** is formed to touch and laterally surround gate **224** and protective cap **225**.

Thin side wall spacer **514**, which is non-conductive, can be formed in a number of ways. For example, a thin layer of oxide can be deposited on gate **224**, protective cap **225**, lightly-doped and heavily-doped source region **230/510**, and lightly-doped and heavily-doped drain region **232/512**, followed by the anisotropic etch of the thin layer of oxide until the top surface of protective cap **225** has been exposed to form thin sidewall spacer **514**.

As shown in FIG. 5E, after thin sidewall spacer **514** has been formed, a raised source region **520** is epitaxially grown on heavily-doped source region **510**, while a raised drain region **522** is epitaxially grown on heavily-doped drain region **512** at the same time. The raised source region **520** and the raised drain region **522** are grown using conventional procedures.

Lightly-doped source region **230**, heavily-doped source region **510**, and raised source region **520** form a source **530**, while lightly-doped drain region **232**, heavily-doped drain region **512**, and raised drain region **522** form a drain **532**. The source and drain regions **530** and **532** define a channel region **534** of substrate region **212** that lies between and separates the source and drain regions **530** and **532**. Further, the implant also forms a MOS transistor structure **540**. Following this, MOS transistor structure **540** is annealed, and method **500** continues with conventional steps. The out diffusion from the heavily-doped source and drain regions **510** and **512** heavily dopes the raised source and drain regions **520** and **522**, respectively.

One of the advantages of method **500** is that method **500** utilizes a first sidewall spacer **508** to form the heavily-doped source and drain regions **510** and **512**, and a second different sidewall spacer **514** to form the raised source region **520** and the raised drain region **522**. By using two different sidewall spacers, the widths of the sidewall spacers can be adjusted to optimize the sizes of both the heavily-doped regions and the raised regions.

FIG. 6 shows a cross-sectional view that illustrates an example of a raised source/drain MOS transistor **600** in accordance with an alternate embodiment of the present invention. MOS transistor **600** is similar to MOS transistor **400** and, as a result, utilizes the same reference numerals to designate the structures which are common to both transistors.

As shown in FIG. 6, MOS transistor **600** differs from MOS transistor **400** in that MOS transistor **600** utilizes a sidewall spacer **610** in lieu of sidewall spacer **432**. Sidewall spacer **610** is the same as sidewall spacer **132** and **432**, except that sidewall spacer **610** is wider than either sidewall spacer **132** or sidewall spacer **432**.

In addition, sidewall spacer **610** also touches and lies over the top surface of raised source region **520** and the top surface raised drain region **522**, whereas sidewall spacer **132** does not touch and lie over the top surface of the raised source region **120E** and the top surface of raised drain region **122E**. Further, the maximum width **WX** of sidewall spacer **610** is substantially greater than a minimum distance **DY** that separates raised source region **420E** from gate **130**.

FIGS. 7A-7D show cross-sectional views that illustrate an example of a method **700** of forming a raised source/drain MOS transistor in accordance with an alternate embodiment of the present invention. Method **700** is similar to method **200** and, as a result, utilizes the same reference numerals to designate the structures that are common to both methods.

Method **700** is the same as method **200** up through the formation of the lightly-doped source and drain regions **230** and **232** shown in FIG. 2C, and differs from method **200** in

that, as shown in FIG. 7A, method **700** next forms a thin sidewall spacer **708** to touch and laterally surround gate **224** and protective cap **225**.

Thin side wall spacer **708**, which is non-conductive, can be formed in a number of ways. For example, a thin layer of oxide can be deposited on gate **224**, protective cap **225**, lightly-doped source region **230**, and lightly-doped drain region **232**, followed by the anisotropic etch of the thin layer of oxide until the top surface of protective cap **225** has been exposed to form thin sidewall spacer **708**.

As shown in FIG. 7B, after thin sidewall spacer **708** has been formed, a raised source region **710** is epitaxially grown on lightly-doped source region **230**, while a raised drain region **712** is epitaxially grown on lightly-doped drain region **232** at the same time. The raised source region **710** and the raised drain region **712** are grown using conventional procedures.

As shown in FIG. 7C, after the raised source and drain regions **710** and **712** have been formed, a wide sidewall spacer **714** is formed to touch and laterally surround gate **224** and protective cap **225**. Wide side wall spacer **714**, which is non-conductive, can be formed in a number of ways.

For example, a layer of oxide can be deposited on protective cap **225**, sidewall spacer **708**, raised source region **710**, and raised drain region **712**, followed by an anisotropic etch of the layer of oxide until the top surface of protective cap **225** has been exposed to form a sidewall spacer **716**. In this example, sidewall spacer **708** and sidewall spacer **716** in combination form wide sidewall spacer **714**.

Alternately, wide sidewall spacer **714** can be formed by first removing sidewall spacer **708**. After this, wide sidewall spacer **714** is formed by depositing a thick layer of oxide, followed by an anisotropic etch of the thick layer of oxide until the top surface of protective cap **225** has been exposed to form a sidewall spacer **716**.

As shown in FIG. 7D, after wide sidewall spacer **714** has been formed, a dopant is implanted into substrate region **212** and the lightly-doped source and drain regions **230** and **232** using conventional procedures to form spaced-apart heavily-doped source and drain regions **720** and **722**. Heavily-doped source region **720** touches both substrate region **212** and lightly-doped source region **230**, while heavily-doped drain region **722** touches both substrate region **212** and lightly-doped drain region **232**.

Lightly-doped source region **230**, heavily-doped source region **720**, and raised source region **710** form a source **730**, while lightly-doped drain region **232**, heavily-doped drain region **722**, and raised drain region **712** form a drain **732**. The source and drain regions **730** and **732** define a channel region **734** of substrate region **212** that lies between and separates the source and drain **730** and **732**. Further, the implant also forms a MOS transistor structure **740**. Following this, MOS transistor structure **740** is annealed, and method **700** continues with conventional steps.

FIG. 8 shows a cross-sectional view that illustrates an example of a raised source/drain MOS transistor **800** in accordance with an alternate embodiment of the present invention. MOS transistor **800** is similar to MOS transistor **400** and, as a result, utilizes the same reference numerals to designate the structures which are common to both transistors.

As shown in FIG. 8, MOS transistor **800** differs from MOS transistor **400** in that MOS transistor **800** utilizes a body **810** in lieu of body **410**. Body **810**, in turn, is the same as body **410** except that body **810** utilizes a source **820** in lieu of source **420**. Source **820** includes a lightly-doped source region **820L**, a heavily-doped source region **820H**, and a raised source

11

region **820E**, each of which has a conductivity type that is the opposite of the conductivity type of substrate region **112**.

Lightly-doped source region **820L** touches substrate region **112**, and heavily-doped source region **820H** touches both substrate region **112** and lightly-doped source region **820L**. In addition, raised source region **820E**, which is heavily-doped, touches and lies above the top surface of heavily-doped source region **820H**. All of raised source region **820E** also lies laterally spaced apart from sidewall spacer **432**.

Further, raised source region **820E** is spaced apart from a portion of the top surface of heavily-doped source region **820H**. Raised source region **820E** also has a maximum width **WR**, a maximum depth **D** that is orthogonal to the maximum width **WR**, and a length that is orthogonal to the maximum width **WR** and the maximum depth **D**.

Heavily-doped source region **820H** also has a maximum width **WS**, a depth measured parallel to the maximum depth **D**, and a length measured parallel to the length of raised source region **820E**. As additionally shown in FIG. 8, the maximum width **WS** of heavily-doped source region **820H** is substantially larger than the maximum width **WR** of raised source region **820E**.

Body **810** also differs from body **410** in that body **810** utilizes a drain **822** in lieu of drain **422**. Drain **822** includes a lightly-doped drain region **822L**, a heavily-doped drain region **822H**, and a raised drain region **822E**, each of which has a conductivity type that is the opposite of the conductivity type of substrate region **112**.

Lightly-doped drain region **822L** touches substrate region **112**, and heavily-doped drain region **822H** touches both substrate region **112** and lightly-doped drain region **822L**. Raised drain region **822E**, which is heavily doped, touches and lies above the top surface of heavily-doped drain region **822H**. All of raised drain region **822E** also lies laterally spaced apart from sidewall spacer **432**. In addition, the top surface of raised source region **820E** and the top surface of the raised drain region **822E** lie in a plane that passes through gate **130**, where the plane lies above the bottom surface of gate **130**.

Further, raised drain region **822E** is spaced apart from a portion of the top surface of heavily-doped drain region **822H**. Raised drain region **822E** also has a maximum width **WT**, a maximum depth measured parallel to the maximum depth **D**, and a length that is measured parallel to the length of the raised drain region **822E**.

As additionally shown in FIG. 8, the maximum width **WU** of heavily-doped source region **822H** is substantially larger than the maximum width **WT** of raised source region **820E**. In addition, a portion of the top surface of heavily-doped drain region **822H** is spaced apart from raised drain region **822E**.

The source **820** and drain **822**, which are spaced apart, also define a channel region **824** at the top surface of substrate region **112** that lies between and separates source **820** and drain **822**. In addition, since channel region **824** is a part of substrate region **112**, channel region **824** has the same conductivity type as substrate region **112**.

FIGS. 9A-9C show cross-sectional views that illustrate an example of a method **900** of forming a raised source/drain MOS transistor in accordance with an alternate embodiment of the present invention. Method **900** is similar to method **500** and, as a result, utilizes the same reference numerals to designate the structures that are common to both methods.

Method **900** is the same as method **500** up through the formation of wide sidewall spacer **508** shown in FIG. 5A, and differs from method **500** in that, as shown in FIG. 9A, method **900** next epitaxially grows a raised source region **910** on lightly-doped source region **230**, while epitaxially growing a

12

raised drain region **912** on lightly-doped drain region **232** at the same time. The raised source region **910** and the raised drain region **912** are grown using conventional procedures.

As shown in FIG. 9B, after the raised source and drain regions **910** and **912** have been formed, wide sidewall spacer **508** is removed using conventional etchants and procedures. As shown in FIG. 9C, after wide sidewall spacer **508** has been removed, a thin sidewall spacer **914** is formed to touch and laterally surround gate **224** and protective cap **225**. Thin side wall spacer **914**, which is non-conductive, is horizontally spaced apart from all of raised source region **910** and all of raised drain region **912**.

Thin side wall spacer **914** can be formed in a number of ways. For example, a thin layer of oxide can be deposited on gate **224**, protective cap **225**, lightly-doped source region **230**, lightly-doped drain region **232**, raised source region **910**, and raised drain region **912**, followed by the anisotropic etch of the thin layer of oxide until the top surface of protective cap **225** has been exposed to form thin sidewall spacer **914**.

After thin sidewall spacer **914** has been formed, a dopant is implanted into substrate region **212** and the lightly-doped source and drain regions **230** and **232** using conventional procedures to form spaced-apart heavily-doped source and drain regions **920** and **922**. Heavily-doped source region **920** touches both substrate region **212** and lightly-doped source region **230**, while heavily-doped drain region **922** touches both substrate region **212** and lightly-doped drain region **232**. The implant also heavily dopes raised source region **910** and raised drain region **912**.

Lightly-doped source region **230**, heavily-doped source region **920**, and raised source region **910** form a source **930**, while lightly-doped drain region **232**, heavily-doped drain region **922**, and raised drain region **912** form a drain **932**. The source and drain regions **930** and **932** define a channel region **934** of substrate region **212** that lies between and separates the source and drain **930** and **932**. Further, the implant also forms a MOS transistor structure **940**.

Following this, MOS transistor structure **940** is annealed to drive in the implant. The anneal causes the heavily-doped source and drain regions **920** and **922** to expand slightly into the lightly-doped source and drain regions **230** and **232** due to out diffusion. However, the difference in the maximum widths between raised source region **910** and heavily-doped source region **920**, although partly due to out diffusion, is primarily due to the different widths of the sidewall spacers **508** and **914**. As a result, the maximum width of heavily-doped source region **920** is substantially larger than the maximum width of raised source region **910**.

Similarly, the difference in the maximum widths between raised drain region **912** and heavily-doped drain region **922**, although partly due to out diffusion, is primarily due to the different widths of the sidewall spacers **508** and **914**. As a result, the maximum width of heavily-doped drain region **922** is substantially larger than the maximum width of raised drain region **912**. Following this, method **900** continues with conventional steps.

FIG. 10 shows a cross-sectional view that illustrates an example of a raised source/drain MOS transistor **1000** in accordance with an alternate embodiment of the present invention. MOS transistor **1000** is similar to MOS transistor **800** and, as a result, utilizes the same reference numerals to designate the structures which are common to both transistors.

As shown in FIG. 10, MOS transistor **1000** differs from MOS transistor **800** in that MOS transistor **1000** utilizes a sidewall spacer **1010** in lieu of sidewall spacer **432**. Sidewall spacer **1010** is the same as sidewall spacer **432**, except that

13

sidewall spacer 1010 is wider than sidewall spacer 432. In addition, sidewall spacer 1010 also touches raised source region 820E and raised drain region 822E, whereas sidewall spacer 432 does not touch raised source region 820E and raised drain region 822E.

FIGS. 11A-11C show cross-sectional views that illustrate an example of a method 1100 of forming a raised source/drain MOS transistor in accordance with an alternate embodiment of the present invention. Method 1100 is similar to method 700 and, as a result, utilizes the same reference numerals to designate the structures that are common to both methods.

Method 1100 is the same as method 700 up through the formation of thin sidewall spacer 708 shown in FIG. 7A, and differs from method 700 in that, as shown in FIG. 11A, method 1100 next implants a dopant into substrate region 212 and the lightly-doped source and drain regions 230 and 232 using conventional procedures to form spaced-apart heavily-doped source and drain regions 1110 and 1112. Heavily-doped source region 1110 touches both substrate region 212 and lightly-doped source region 230, while heavily-doped drain region 1112 touches both substrate region 212 and lightly-doped drain region 1112.

As shown in FIG. 11B, after the heavily-doped source and drain regions 1110 and 1112 have been formed, a wide sidewall spacer 1114 is formed to touch and laterally surround gate 224 and protective cap 225. Wide side wall spacer 1114, which is non-conductive, can be formed in a number of ways.

For example, a layer of oxide can be deposited on protective cap 225, sidewall spacer 708, raised source region 1120, and raised drain region 1122, followed by an anisotropic etch of the layer of oxide until the top surface of protective cap 225 has been exposed to form a sidewall spacer 1116. In this example, sidewall spacer 708 and sidewall spacer 1116 in combination form wide sidewall spacer 1114.

Alternately, wide sidewall spacer 1114 can be formed by first removing sidewall spacer 708. After this, wide sidewall spacer 1114 is formed by depositing a thick layer of oxide, followed by an anisotropic etch of the thick layer of oxide until the top surface of protective cap 225 has been exposed to form a sidewall spacer 1116.

As shown in FIG. 11C, after wide sidewall spacer 1114 has been formed, a raised source region 1120 is epitaxially grown on heavily-doped source region 1110, while a raised drain region 1122 is epitaxially grown on heavily-doped drain region 1112 at the same time. The raised source region 1120 and the raised drain region 1122 are grown using conventional procedures.

Lightly-doped source region 230, heavily-doped source region 1110, and raised source region 1120 form a source 1130, while lightly-doped drain region 232, heavily-doped drain region 1112, and raised drain region 1122 form a drain 1132. The source and drain regions 1130 and 1132 define a channel region 1134 of substrate region 212 that lies between and separates the source and drain 1130 and 1132. Further, the implant also forms a MOS transistor structure 1140.

Following this, MOS transistor structure 1140 is annealed to drive in the implant. The anneal causes the heavily-doped source and drain regions 1110 and 1112 to expand slightly into the lightly-doped source and drain regions 230 and 232 due to out diffusion. However, the difference in the maximum widths between raised source region 1120 and heavily-doped source region 1110, although partly due to out diffusion, is primarily due to the different widths of the sidewall spacers 708 and 1114. As a result, the maximum width of heavily-doped source region 1110 is substantially larger than the maximum width of raised source region 1120.

14

Similarly, the difference in the maximum widths between raised drain region 1122 and heavily-doped drain region 1112, although partly due to out diffusion, is primarily due to the different widths of the sidewall spacers 708 and 1114. As a result, the maximum width of heavily-doped drain region 1112 is substantially larger than the maximum width of raised drain region 1122. The out diffusion from the heavily-doped source and drain regions 1110 and 1112 also heavily dopes the raised source and drain regions 1120 and 1122, respectively. Following this, method 1100 continues with conventional steps.

It should be understood that the above descriptions are examples of the present invention, and that various alternatives of the invention described herein may be employed in practicing the invention. Thus, it is intended that the following claims define the scope of the invention and that structures and methods within the scope of these claims and their equivalents be covered thereby.

What is claimed is:

1. A method of forming a semiconductor structure comprising:

forming a gate structure that includes a gate dielectric that touches and lies above a semiconductor region, and a gate that touches and lies above the gate dielectric;

implanting the semiconductor region after the gate structure has been formed to form a lightly-doped source region and a lightly-doped drain region that touch the semiconductor region;

forming a first sidewall spacer that touches and laterally surrounds the gate structure;

implanting the semiconductor region, the lightly-doped source region, and the lightly-doped drain region after the first sidewall spacer has been formed to form a heavily-doped source region and a heavily-doped drain region, the heavily-doped source region touching the semiconductor region and the lightly-doped source region, the heavily-doped drain region touching the semiconductor region and the lightly-doped drain region;

forming a second sidewall spacer that touches and laterally surrounds the gate structure after the heavily-doped source region and the heavily-doped drain region have been formed;

epitaxially growing a raised source region that touches the heavily-doped source region, and a raised drain region that touches the heavily-doped drain region after the second sidewall spacer has been formed; and

removing the first sidewall spacer after the heavily-doped source region and the heavily-doped drain region have been formed and before the second sidewall spacer is formed.

2. The method of claim 1 wherein the heavily-doped source region has a width, the raised source region has a width, and the width of the raised source region is greater than the width of the heavily-doped source region.

3. A method of forming a semiconductor structure comprising:

forming a gate structure that includes a gate dielectric that touches and lies above a semiconductor region, and a gate that touches and lies above the gate dielectric;

implanting the semiconductor region after the gate structure has been formed to form a lightly-doped source region and a lightly-doped drain region that touch the semiconductor region;

forming a first sidewall spacer that touches and laterally surrounds the gate structure;

implanting the semiconductor region, the lightly-doped source region, and the lightly-doped drain region after the first sidewall spacer has been formed to form a heavily-doped source region and a heavily-doped drain region, the heavily-doped source region touching the semiconductor region and the lightly-doped source region, the heavily-doped drain region touching the semiconductor region and the lightly-doped drain region;  
forming a second sidewall spacer that touches and laterally surrounds the gate structure after the heavily-doped source region and the heavily-doped drain region have been formed; and  
epitaxially growing a raised source region that touches the heavily-doped source region, and a raised drain region that touches the heavily-doped drain region after the second sidewall spacer has been formed;  
wherein forming the second sidewall spacer includes forming a third sidewall spacer to touch and laterally surround the first sidewall spacer, a combination of the first sidewall spacer and the third sidewall spacer forming the second sidewall spacer, and  
wherein the heavily-doped source region has a width, the raised source region has a width, and the width of the heavily-doped source region is substantially greater than the width of the raised source region.

\* \* \* \* \*